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Aerosol property retrievals with the use of an airborne compact multi-angle polarimeter (C-MAP)

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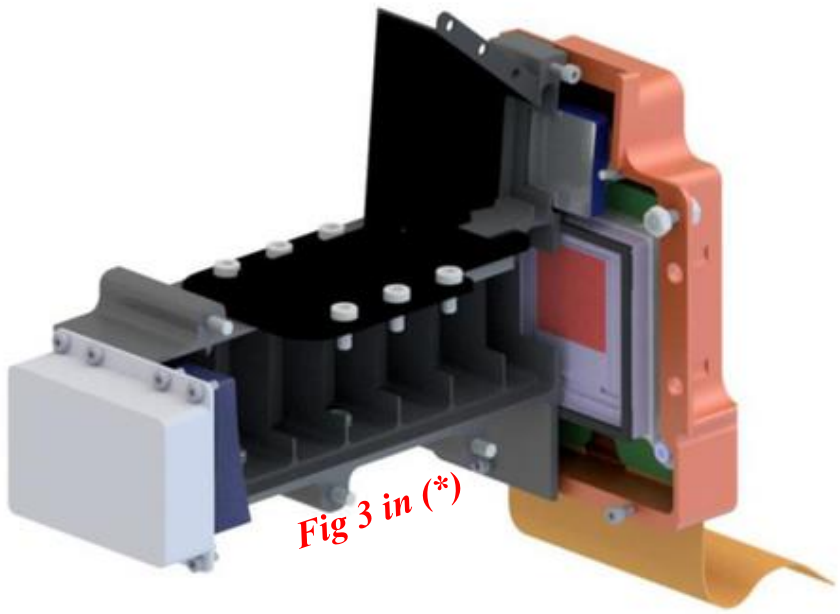
C-MAP instrument



- *C-MAP*: Compact, Multi-Angle, multi-spectral Polarimeter
- Airborne demonstrator adapted from the MAP/CO2M
- Measurement principle:
  - Measures the polarization of sunlight reflected on the Earth's surface → $\boldsymbol{S} = [I, Q, U, V]^T$
- Operation principle:
  - Multiple views of the same target on the ground, multiple spectral bands
  - *MAPs can be extremely useful for aerosol studies*
  - *Polarization + multiple views => more information*
- Targeted accuracies: 3% for I, 0.003 for DoLP

(*) *Spilling, D. and Walker, A., 2021*

Past, present and future satellite/airborne polarimetric missions and sensors

1996 → 2025…

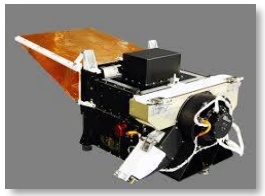
POLDER 1-2

8 wls,
3 polarized,

14 angular views,

± 43°/ ± 51° along/across track scan,

spatial resolution: 6 × 7 km at nadir



RSP

9 wls,
all polarized,

152 angular views,

± 60° with respect to nadir

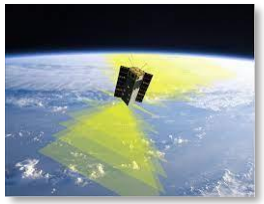
POLDER 3

9 wls,
3 polarized,

16 angular views,

± 43°/ ± 51° along/across track scan,

spatial resolution: 6 × 7 km at nadir



HARP/CubeSat

4 wls,
all polarized,

60 angular views for 670 nm;
20 angular views for other wls,

114°/94° along/across track scan,

spatial resolution: 3 km

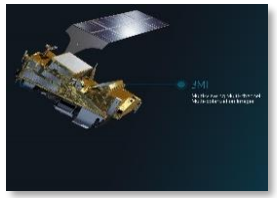
AirHARP

4 wls,
all polarized,

60 angular views for 670 nm;
20 angular views for other wls,

94°/114° across/along track scan,

spatial resolution: 20 m



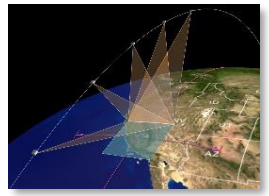
3MI

12 wls,
9 polarized,

10 to 14 angular views,

± 50°/ ± 50° along/across track scanz,

spatial resolution: 4km at nadir



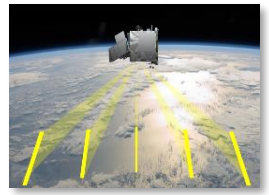
MAIA/OTB-2

14 wls,
3 polarized,

5–9 view angles per scene,

365/235 km along/across track scan,

spatial resolution ~200 m at nadir



SpexOne and HARP2/PACE

SpexOne: Hyperspectral measurements in the range 385–770 nm,

5 angular views between ± 57°,

spatial resolution 5 km

HARP2 – as HARP and AirHARP

MAP/CO2M

8 wls,
all polarized

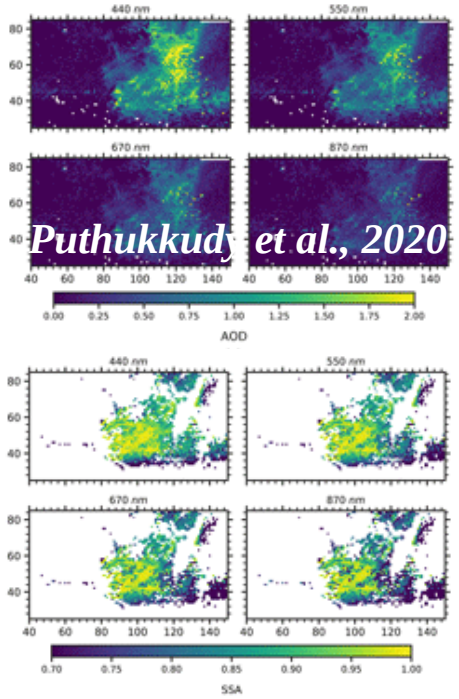
40 angular views between ± 60°,

spatial resolution 4 × 4 km off-nadir,

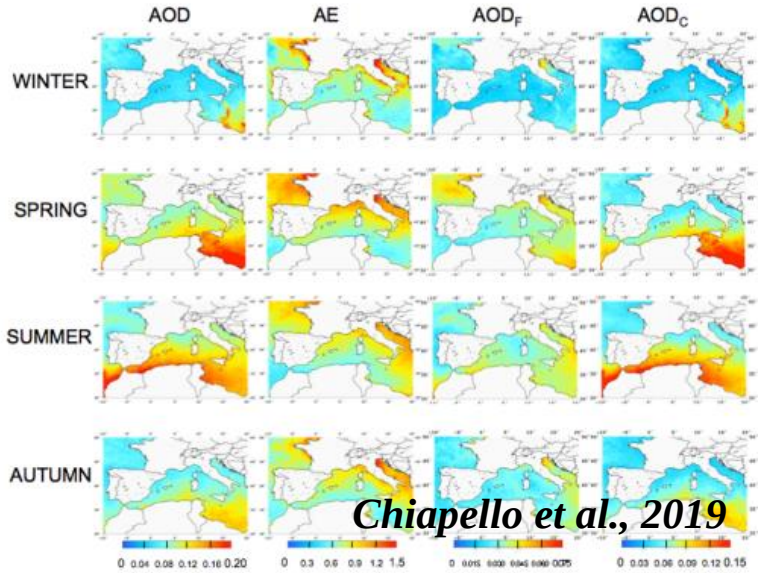
… and more (see *Dubovik et al., 2019*)

Example applications

Aerosol optical properties

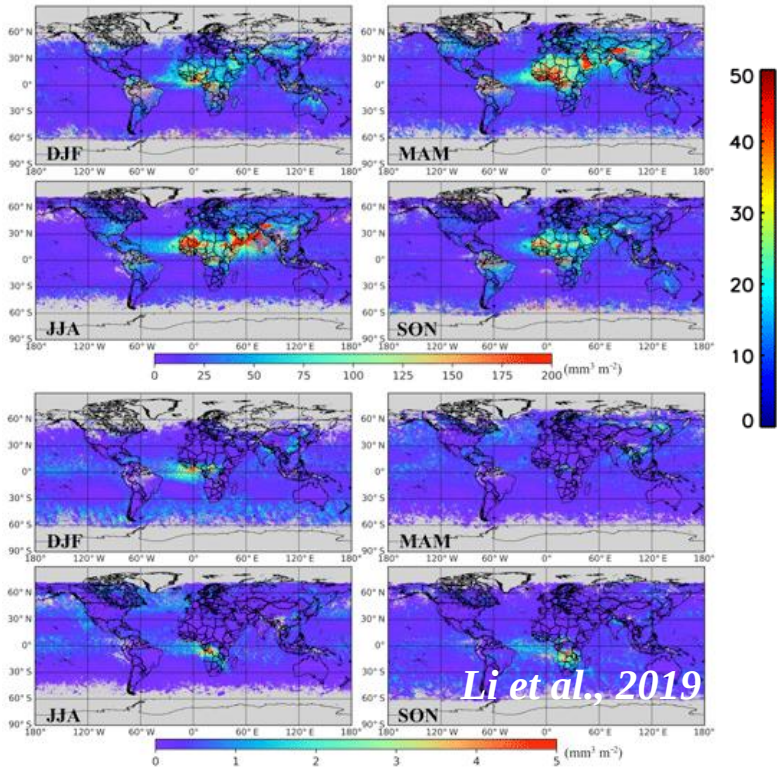


Puthukkudy et al., 2020



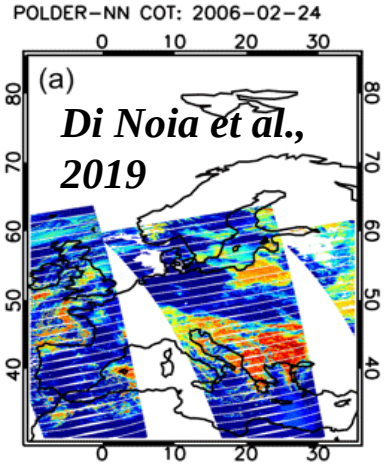
Chiapello et al., 2019

Aerosol column volume concentration

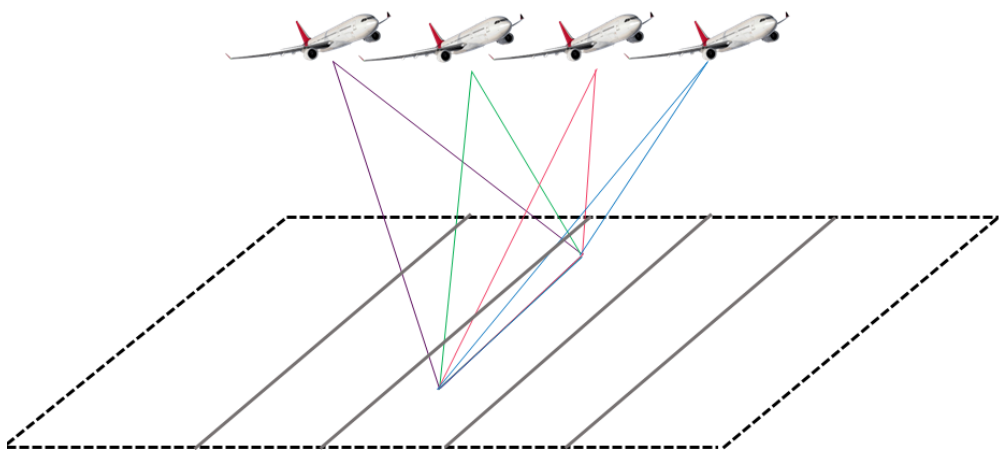


Li et al., 2019

Cloud optical thickness



Di Noia et al., 2019

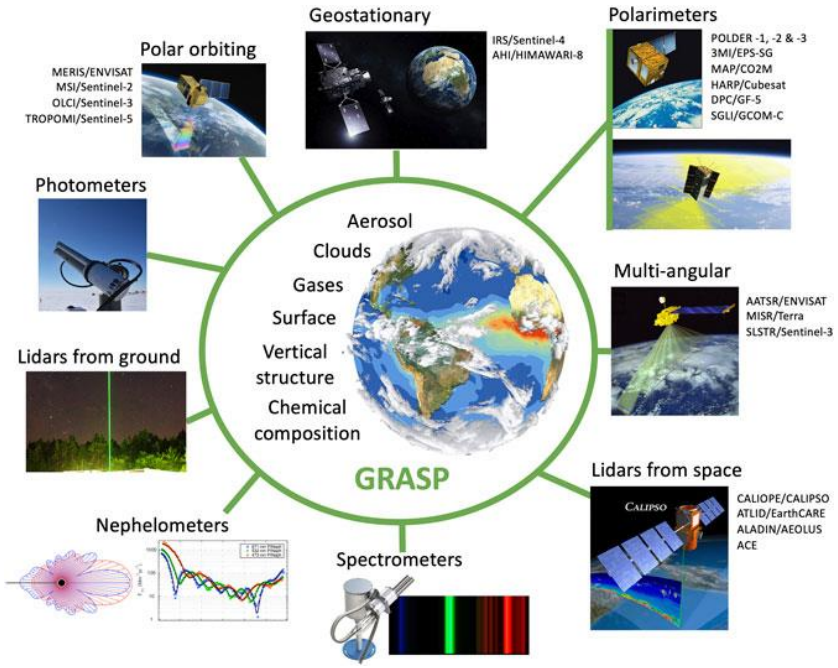


C-MAP characteristics

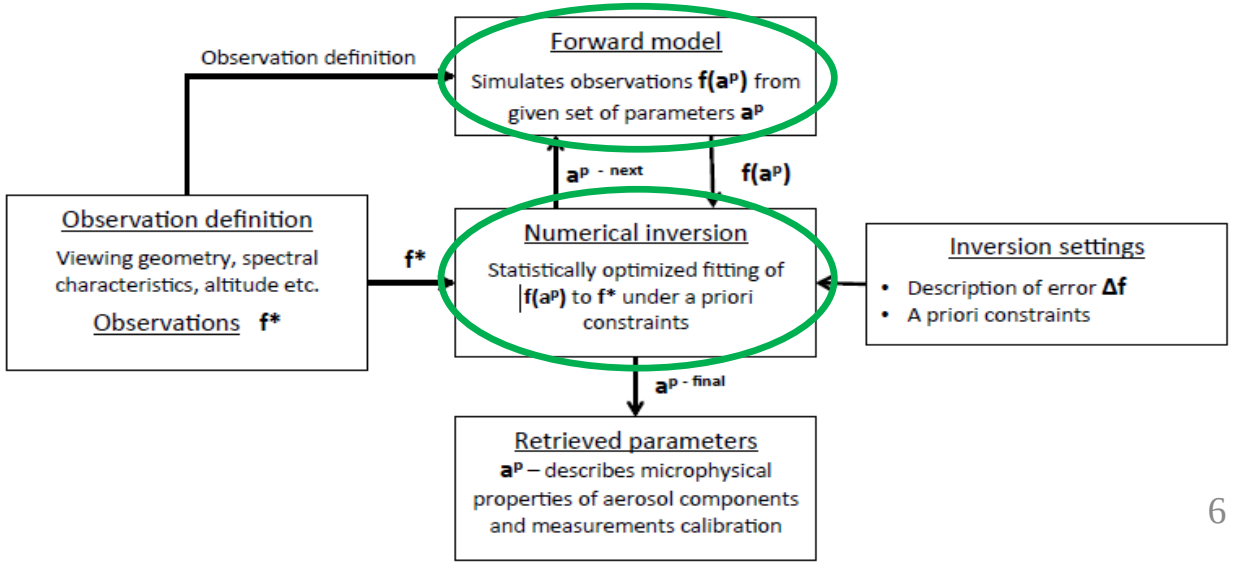
- ✓ 7 bands in visible and near-infrared: 410, 443, 490, 555, 670, 865nm
- ✓ Measurements of I, Q and U (→ DoLP)
- ✓ >40 different viewing angles
- ✓ System design follows the CO2M/MAP design developed from TAS-UK (*) → *difference: single camera*
- ✓ *Compact* and *light-weight*, can work even on low cost CubeSats or similar platforms

(*) Spilling, D. and Walker, A., 2021

Aerosol property retrievals with GRASP*



- ✓ Open source retrieval algorithm
- ✓ Aerosol and surface properties
- ✓ Highly versatile, can facilitate a large variety of input data (active/passive remote sensing sensors, in-situ data, ground-based/airborne/satellite)
- ✓ Can be used for measurements above different surfaces (i.e. bright surfaces like deserts)
- ✓ Includes 2 independent modules:

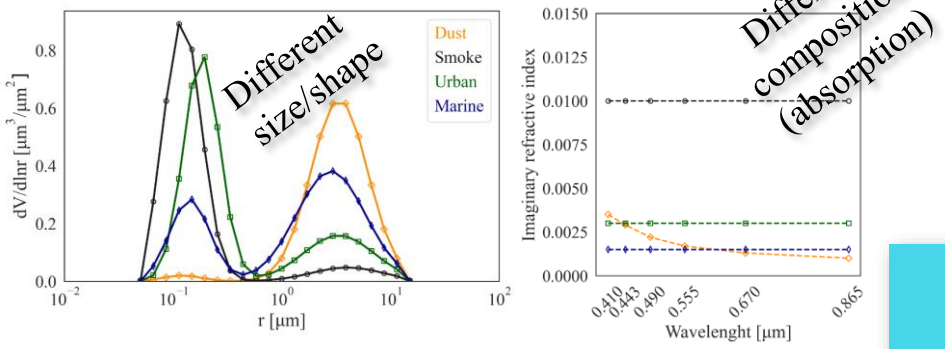


* *Generalized Retrieval of Aerosol and Surface Properties (Dubovik et al., 2011; 2021)*

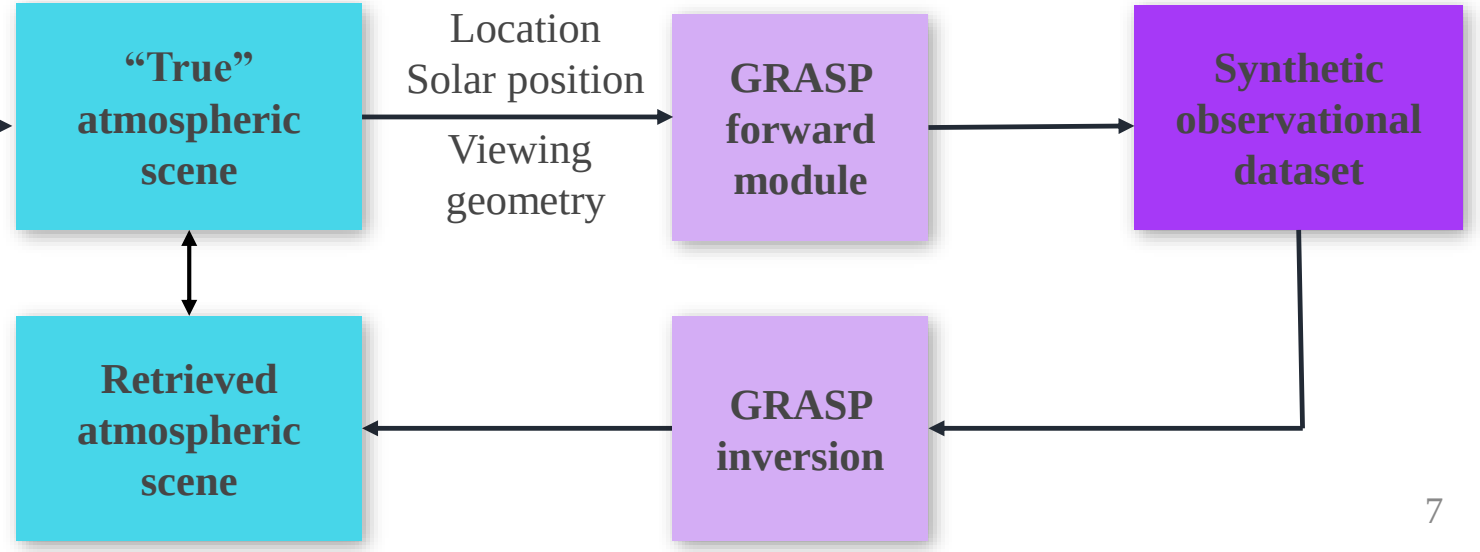
Description of sensitivity study

- ✓ Assess the retrieval of aerosol properties (shape, size, composition) using C-MAP radiance and polarization measurements
- ✓ Quantify the uncertainty of the retrieved properties
- ✓ For measurement campaign: define measurement strategy for optimum retrievals (e.g. time of the day, SPP measurements)
- ✓ Evaluate instrument performance over different land types

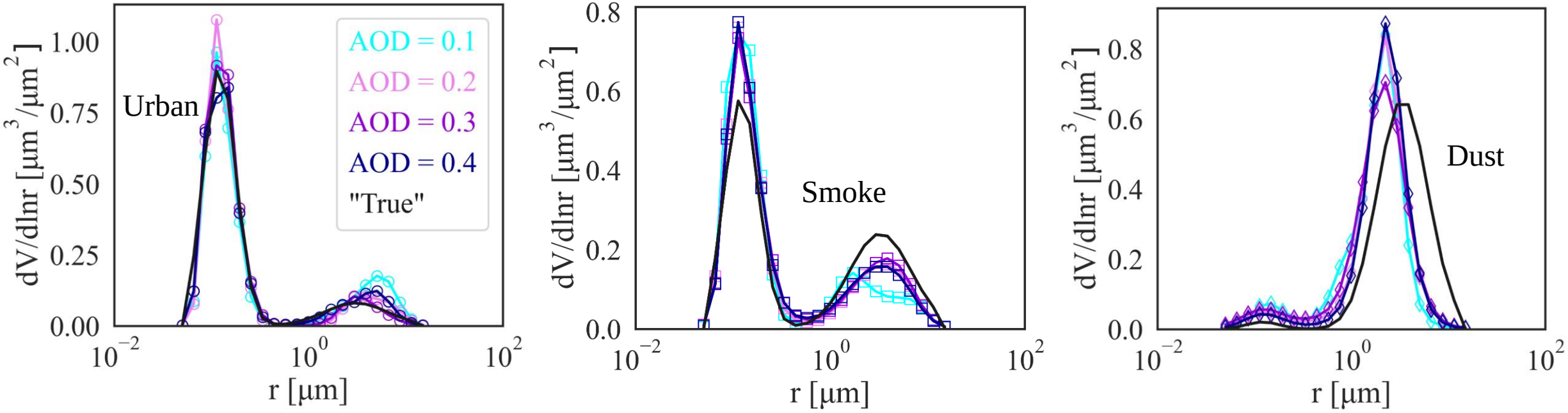
AERONET climatology



GRASP/POLDER and MODIS climatology



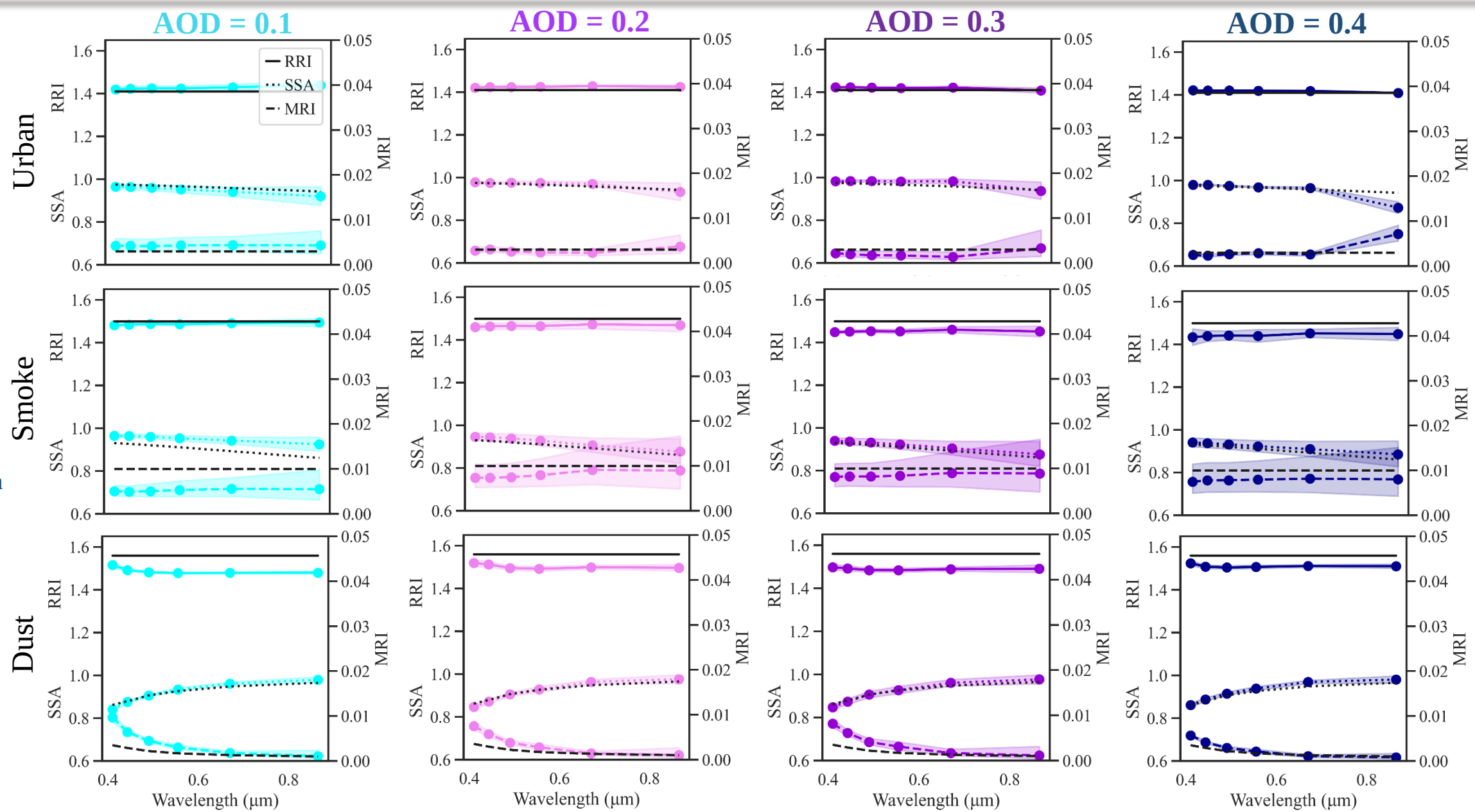
Preliminary results – Size distribution (single pixel retrieval, grassland, sza = 55º, plane trajectory aligned with SPP)



	$<r_{eff(f)}>$ (µm)	$\varepsilon_{reff(f)}$ (µm) AOD_{440} = 0.1 – AOD_{440} = 0.4	$<r_{eff(c)}>$ (µm)	$\varepsilon_{reff(c)}$ (µm) AOD_{440} = 0.1 – AOD_{440} = 0.4
Urban	0.12	-0.01 – (-0.03)	3.35	1.13 – 0.8
Smoke	0.12	0.002 – (- 0.006)	2.33	0.5 – 0.15
Dust	0.13	-0.002 – (-0.003)	1.85	-1.3 – (-0.6)

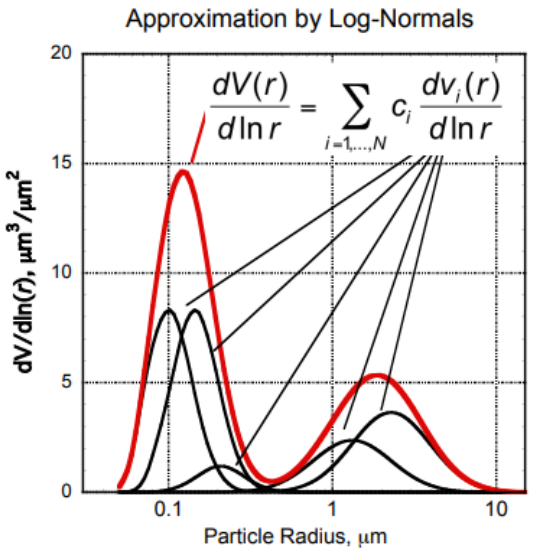
Preliminary results – complex refractive index and single scattering albedo

(single pixel retrieval, grassland, sza = 55°, plane trajectory aligned with SPP)



Key findings so far

- *Fine mode r_{eff} for all aerosol models are retrieved quite well*
- *Coarse mode is challenging*
  - C-MAP measurements mainly in the visible → not enough information for larger particles
  - Narrow scattering angle range (~50 - 180º) → no information from forward scattering
- To improve the CRI and SSA retrievals, the number of parameters to be retrieved can be decreased
  - This methodology has been successfully applied for POLDER/PARASOL*, AirHARP** and 3MI*** multi-angle, multi-spectral polarization measurements



* *Dubovik et al., 2011*
** *Puthukkudy et al., 2020*
*** *ERA - Enhanced Retrieval of Aerosol properties: reference and NRT algorithm prototype for 3MI mission, 2018*

Future work

- *Two demonstrator flights with C-MAP are scheduled in the UK for late 2022*
  - Validation: Overflights of UK AERONET stations
  - Potentially align with an overpass of the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)

- *Instrument testing on the ground in the remote sensing observatory of Space Park Leicester:*
  - C-MAP
  - Multi-wavelength sun/sky radiometer with polarization capability (part of the AERONET* network)
  - Polarization lidar @355nm (following ACTRIS** standards)
  - MAX-DOAS spectrometer
    - Explore C-MAP sensitivity for ground based measurements
    - Synergistic retrievals (i.e. with lidar (profiling) or MAX-DOAS spectrometer)
    - Validate against CIMEL sun/sky radiometer retrievals

* *Worldwide AErosol RObotic NETwork (https://aeronet.gsfc.nasa.gov/)*
** *Pan-European Aerosol Clouds and Trace Gases Research Infrastructure (https://www.actris.eu/)*

Acknowledgements

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The authors would like to thank GRASP team for making the algorithm available (https://www.grasp-open.com/)